Constrain intergalactic medium from the SZ effect map

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ABSTRACT

In this paper, we try to detect the SZ effect in the 2MASS DWT clusters and less bound objects in order to constrain the warm-hot intergalactic medium distribution on large scales by cross-correlation analysis. The results of both observed WMAP and mock SZ effect map indicate that the hot gas distributes from inside as well as outside of the high density regions of galaxy clusters, which is consistent with the results of both observation and hydro simulation. Therefore, the DWT measurement of the cross-correlation would be a powerful tool to probe the missing of baryons in the Universe.

Subject headings: cosmology: theory - large-scale structure of the universe

1. Introduction

The Sunyaev-Zeldovich(SZ) effect, or the inverse-Compton scattering of the cosmic microwave background (CMB) photons by hot electrons, shifts the spectrum of the CMB photons to higher energy when the photons pass through the regions of cosmic hot gas.

Since galaxy clusters are major hosts of hot gas and hot electrons, the SZ effect would lead to a correlation between the maps of the CMB temperature fluctuations and the distribution of galaxies on scales of clusters. Several groups have claimed the detection of SZ effect signal with the cross-correlation between first year WMAP data and samples of galaxy clusters. Hernández-Monteagudo & Rubiño-Martín(2004) performed a cross-correlation test between 2MASS and WMAP for small patches on the sky and found a strong detection; Afshordi et al.(2004) detected the SZ effect at 3σ level on small angular scales by cross-correlating the WMAP data with the 2MASS galaxy catalogue; Fosalba et al.(2004) reported

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a detection of the SZ effect cross-correlating the WMAP data with large scale structure traced by the SDSS data.

While Tukugita & Peebles(2004) have argued that about 90% of all baryons are in the form of intergalactic plasma, but the observational results on the properties of the intra-cluster medium are quite uncertain, amount to $\approx 35\%$ of the total are missing(Tukugita 2003). Since the SZ effect are significantly indicated by cross-correlation,which makes the SZ detection a powerful tool to constrain the hot gas in- and outside of clusters of galaxies.

However, all these above detections of the SZ effect were found mainly on small angular scales and mostly due to clusters. Recently, there are also several authors focus on the cross-correlation between WMAP and less bound objects such as loose groups or super-clusters. Myers et al.(2004) cross-correlated the WMAP data with the APM,ACO and 2MASS catalogues and detect a SZ effect out to $\sim 1°$ angular distance of the cluster centers, which are interpreted as evidence of cluster plasma as well as super-cluster hot gas. With the X-ray based catalogues, Hernández-Monteagudo et al.(2004) also detect significant SZ effect from the clusters, but did not find SZ evidence from super-clusters. These two discrepant results motivate us care for the uncertainty to the model of gas distribution, not simply assume that hot gas are traced by galaxies.

We used the 2MASS extended source catalog and developed a biased gas distribution model to study the SZ effect from clusters and super-clusters. The SZ effects from 2MASS galaxies have been unanimously detected(Myers et al. 2004; Afshordi et al. 2004), which would be useful to test our results.The cross-correlation statistics of this paper are based on the discrete wavelet transform (DWT), which is more sensitive to detect the SZ effect(Cao et al. 2006).

The paper is organized as follows. §2 describes the DWT algorithm used in this paper. In §3,we perform the cross-correlation analysis to constrain the hot gas in both clusters and super-clusters through their SZ effect detection. The discussion and conclusion are given in §4.

2. Discrete wavelet transform(DWT) method

2.1. The DWT variables

We describe the CMB temperature map and 2MASS galaxy distribution by the variables using the 2-D orthogonal DWT decomposition defined as Cao et al.(2006):

$$\Delta T_{\mathbf{j},\mathbf{l}} = \frac{1}{\int \phi_{\mathbf{j},\mathbf{l}}(\mathbf{x})d\mathbf{x}} \int \Delta T(\mathbf{x})\phi_{\mathbf{j},\mathbf{l}}(\mathbf{x})d\mathbf{x}, \tag{1}$$

$$\rho_{\mathbf{j},\mathbf{l}} = \frac{1}{\int \phi_{\mathbf{j},\mathbf{l}}(\mathbf{x})d\mathbf{x}} \int \rho_g(\mathbf{x})\phi_{\mathbf{j},\mathbf{l}}(\mathbf{x})d\mathbf{x},$$

and

$$\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^T = \int \Delta T(\mathbf{x})\psi_{\mathbf{j},\mathbf{l}}(\mathbf{x})d\mathbf{x}, \tag{2}$$

$$\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^g = \int \rho_g(\mathbf{x})\psi_{\mathbf{j},\mathbf{l}}(\mathbf{x})d\mathbf{x},$$

where $\phi_{\mathbf{j},\mathbf{l}}(\mathbf{x})$ and $\psi_{\mathbf{j},\mathbf{l}}(\mathbf{x})$ are, respectively, the scaling function and wavelet.The $\Delta T_{\mathbf{j},\mathbf{l}}$ and $\rho_{\mathbf{j},\mathbf{l}}$ are called scaling function coefficients (SFCs). For a $\Theta \times \Theta$ 2-D sample,they describe, respectively, the mean temperature and the mean number density of galaxies in the cell $(\mathbf{j},\mathbf{l})$, which has size $\Theta/2^{j_1} \times \Theta/2^{j_2}$ and at position around $(l_1\Theta/2^{j_1}, l_2\Theta/2^{j_1})$, where j_1 and j_2 can be any integral, and $l_1 = 0, ...2^{j_1-1}$, $l_2 = 0, ...2^{j_2-1}$. The angular distance between modes $\mathbf{l}$ and $\mathbf{l}'$ at scale j is given by $\theta = \Theta \times |\mathbf{l} - \mathbf{l}'|/2^j$. The variables $\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^T$ and $\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^g$ are called wavelet function coefficients (WFCs) and describe, respectively, the fluctuations of temperature and galaxy density on scale $\mathbf{j}$ at position $\mathbf{l}$ in wavelet space(Fang & Feng 2000)..

2.2. DWT clusters

The SZ effect is sensitive to hot gas clouds.Since $\rho_{\mathbf{j},\mathbf{l}}$ is proportional to the mean number density of galaxies, one can identify the SZ effect signal with cross-correlation between variables $\Delta T_{\mathbf{j},\mathbf{l}}$ and $\rho_{\mathbf{j},\mathbf{l}}$. In other words, one can picked up top clusters on scale (size) $\mathbf{j}$ by the top members of $\rho_{\mathbf{j},\mathbf{l}}$. These clusters are called DWT clusters(Xu et al. 1999).

Using $\rho_{\mathbf{j},\mathbf{l}}$, we can identify clusters on various scales. $j = 8$ is on the angular scales of $123°.88/2^8 \simeq 0°.5$, which corresponds to $\simeq 1.8 \, h^{-1}$ Mpc at the median redshift of the 2MASS sample. Therefore, we will first identify the DWT clusters from the 2MASS map by the top members of $\rho_{\mathbf{j},\mathbf{l}}$ on scales $j = 8$. For studying the SZ effect from less bound objects, we can also pick up the DWT clusters on scale $j = 7$ as super-clusters.

3. SZ effect detection and intra-cluster hot gas distribution

3.1. Data samples

We used the foreground cleaned WMAP maps of W bands(Bennett et al. 2003), from which the contamination of the galactic foreground other than SZ effect is reduced. This sample is suitable to study the SZ effect.While the galaxy sample are selected from the 2MASS extended source catalog (XSC, Jarrett et al. 2000) with median redshift $z \sim 0.1$.

To carry out the 2-D DWT analysis, we first take the equal-area Lambert azimuthal projection,which projects the whole sky into two circular plane.We then select a $\Theta \times \Theta$ square with $\Theta = 123°.88$ in the central part of each area.

3.2. SZ effect of DWT clusters

With these preparations, we can detect the temperature change of the SZ effect with the cross-correlation between the WMAP data and the 2MASS DWT clusters, defined by

$$\Delta T(|l - l'|) = \langle C_{\mathbf{j},\mathbf{l}}\Delta T_{\mathbf{j},\mathbf{l'}}\rangle, \tag{3}$$

where the variable $C_{\mathbf{j},\mathbf{l}}$ is taken to be 1 for mode(cell) $(\mathbf{j},\mathbf{l})$ corresponding to a DWT cluster on scales j, and $C_{\mathbf{j},\mathbf{l}} = 0$, other modes. The average $\langle ... \rangle$ overs all possible $|l - l'|$ of the sample. Therefore, $\Delta T(|l - l'|)$ is an average CMB temperature fluctuations with a distance $|l - l'|$, or the corresponding angular distance $123°.88|l - l'|/2^j$ from the center of a DWT cluster.

The top panel of Fig. 1 presents the cross correlation ΔT vs.θ of W band map with the top 500 $j = 8$ DWT clusters. The black points and error bars are, respectively, given by the mean and 1-σ of the ensemble $\Delta T(|l - l'|)$ of the considered DWT cluster sample.

It shows an anti-correlation of the DWT clusters at $\theta = 0$ or $l = l'$ with temperature decrease $\Delta T_{sz} \equiv \Delta T - \langle \Delta T \rangle \simeq -15 \pm 10$ μK. This result is about the same as that given by 500 2MASS galaxy groups and clusters selected by friends-of-friends algorithm (Myers et al. 2004). What's more,we can see that the anti-correlation occurs not only at $\theta = 0$, but also slightly at $\theta = 0°.5$. Myers et al.(2004) also found that the strongest anti-correlation is not only at the center of clusters, but on a angular distance larger than a typical clusters. They suggests that it is due to the SZ effect from the super-clusters hot gas.

To detect the SZ effect in less bound objects,we carry the similar cross-correlation for 125 $j = 7$ DWT clusters. We plots ΔT vs. θ for top 125 $j = 7$ DWT clusters in the bottom

panel of Fig. 1. Within error bars,it shows no cross-correlation,i.e., there is no SZ effect due to super-clusters,which is consistent with the results of Hernández-Monteagudo et al.(2004).

Therefore, we conclude that the distribution of hot gas probably is not simply proportional to the number density of optical and infrared galaxies, the biased gas distribution model is needed.

3.3. Biased gas distribution model

With the assumption that galaxies trace hot baryon gas, i.e. $n_e(\mathbf{x}) \propto \rho_g(\mathbf{x})$, Cao et al.(2006) develop a mock SZ effect map as

$$\Delta T_{sz}^{Mock}(\mathbf{x}) = \Delta T_{cmb} - f \frac{\langle (\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^{T})^2 \rangle^{1/2}}{\langle (\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^{g\alpha})^2 \rangle^{1/2}} \rho_g^\alpha(\mathbf{x}), \tag{4}$$

where $\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^{T}$ and $\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^{g\alpha}$ are, respectively, the wavelet variables of $\Delta T_{cmb}(\mathbf{x})$ and $\rho_g^\alpha(\mathbf{x})$. The coefficient $f = \langle (\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^{T_{SZ}})^2 \rangle^{1/2} / \langle (\tilde{\epsilon}_{\mathbf{j},\mathbf{l}}^{T})^2 \rangle^{1/2}$ is the ratio between the powers of SZ effect and CMB temperature fluctuations on scale j, which is set to be 0.1 due to the semi-analytical estimation(e.g. Cooray et al. 2004) in our analysis.

In this paper,we improved the mock SZ effected CMB maps by the follows: $\Delta T_{cmb}(\mathbf{x})$ is given by the HEALPix simulation, $\Delta T_{sz}(\mathbf{x})$ is given by the second term of eq.(4), but $\rho(\mathbf{x})$ is taken to be the value given by the 2MASS map if the position $\mathbf{x}$ is not only at the top 500 modes $(\mathbf{j}, \mathbf{l})$, but also around $|l - l| \leq 1$.

The top panel of Fig.2 plots the cross-correction between the mock SZ effected CMB maps and 500 2MASS DWT clusters, the points and error bars are respectively, the mean and 90% range of 100 mock samples. The mock sample surely yield the expected anti-correlation ΔT decrease at $\theta = 0$ and the tail at $\theta \leq 0.°5$. We also present the cross-correlation between mock SZ effected CMB maps and 125 $j = 7$ 2MASS super-clusters in the bottom panel of Fig.2. Similar to the results of WMAP observed map shown in Fig.1, the super-clusters SZ effect disappeared,which supported again that the biased gas distribution model are consistent with observations.

These results may be interpreted as that the tail of ΔT is from the spread distribution of hot gas around the center of clusters, but not from the super-clusters. The size of $j = 7$ mode is larger than $j = 8$ mode by a factor of 4. However, top $j = 7$ DWT clusters from the 2MASS galaxies are less bounded systems, and generally do not always contain top $j = 8$ DWT clusters.Thus,as the results of both observed and mock samples showed, there no SZ signal can be seen with less bounded systems.

4. Conclusion and discussion

With the cross-correlation between WMAP and 2MASS, we have detect the SZ effect in the 2MASS DWT clusters with temperature decrease $\Delta T_{sz} \equiv \Delta T - \langle \Delta T \rangle \simeq -15 \pm 10 \ \mu K$, while there are no evidence of SZ effect in the less bound objects. This result is consistent with the biased mock SZ effected CMB map. Based on these results,we strongly suggests that the hot gas are not traced by galaxy clusters,but more outspread distributed.

As we have known, the galaxies formation and evolution involves a complex dynamical system of separating baryonic gas and dark matter,which is generally characterized by strong shocks. This feature can be seen with the self-similar solution of spherical collapse under the self-gravity of baryonic gas and dark matter given by Bertschinger(1985). It shows that an outgoing shock is always formed during the infall of baryons. The shocks outgoing from high-density regions can slow down the infall motion of baryons from low-density to collapsed regions,while dark matter is not affected by the shocks. Thus, it can probably leads to the decoupling between the mass and cosmic hot gas.

Our results that the distribution of the baryon fraction is not uniform are consistent with both observations and simulations.The X-ray measurements have revealed that the baryon fraction in galaxy clusters is less than the prediction of primordial nucleosynthesis (Ettori & Fabian 1999). He et al.(2005) used the hydro-simulation to study the spatial dependence cosmic baryons distribution under the mechanism of shocks in nonlinear system, they suggested that about 14% baryons in the universe are "hidden" around the clusters named warm-hot intergalactic medium(WHIM).

On large scales, the non-uniformity of the baryon fraction is a result of the statistical discrepancy of baryonic gas from the underlying galaxy clusters.The baryons can be traced neither by QSO absorption spectrum nor by X-ray emissions. However, the ionized electrons in the outspread baryons would be scatter the CMB photons and contribute to the SZ effect as well. Thus, the SZ effect detection is a powerful tool to probe the missing of baryon matter in the universe.

REFERENCES

Afshordi N., Loh Y.-S., & Strauss M. A. 2004, Phys. Rev. D, 69, 083524

Bennett C. L., et al. 2003, ApJS, 148, 1

Bertschinger, E. 1985, ApJS, 58, 39

Cao, L., Chu,Y.Q., & Fang, L.Z. 2006, MNRAS, in press

Cooray, A., B. Daniel, Sigurdson, K. 2004, astro-ph/0410006

Ettori, S., & Fabian, A.C. 1999, MNRAS, 305, 834

Fang, L.Z. , & Feng, L.L. 2000, ApJ, 539, 5

Fosalba,F., Gaztanaga,E. & Castander,F. 2003, ApJ597,L89-92

Fukugita,.M 2003 astro-ph/0312517

Fukugita,.M , & Peebles,P.J.E. 2004, ApJ, 616,643

He, P., Feng, L.L., & Fang, L.Z. 2005, ApJ, 623,601

Hernández-Monteagudo, C., Genova-Santos R. & Atrio-Barandela, F, 2004, ApJ, 613, L89

Hernández-Monteagudo, C. & Rubiño-Martín, J.A.2004, MNRAS, 347, 403

Jarrett, T. H., et al. 2000, AJ, 119, 2498

Myers, A. D.; Shanks, T.; Outram, P. J.; Frith, W. J.; Wolfendale, A. W. 2004, MN-RAS,347,67
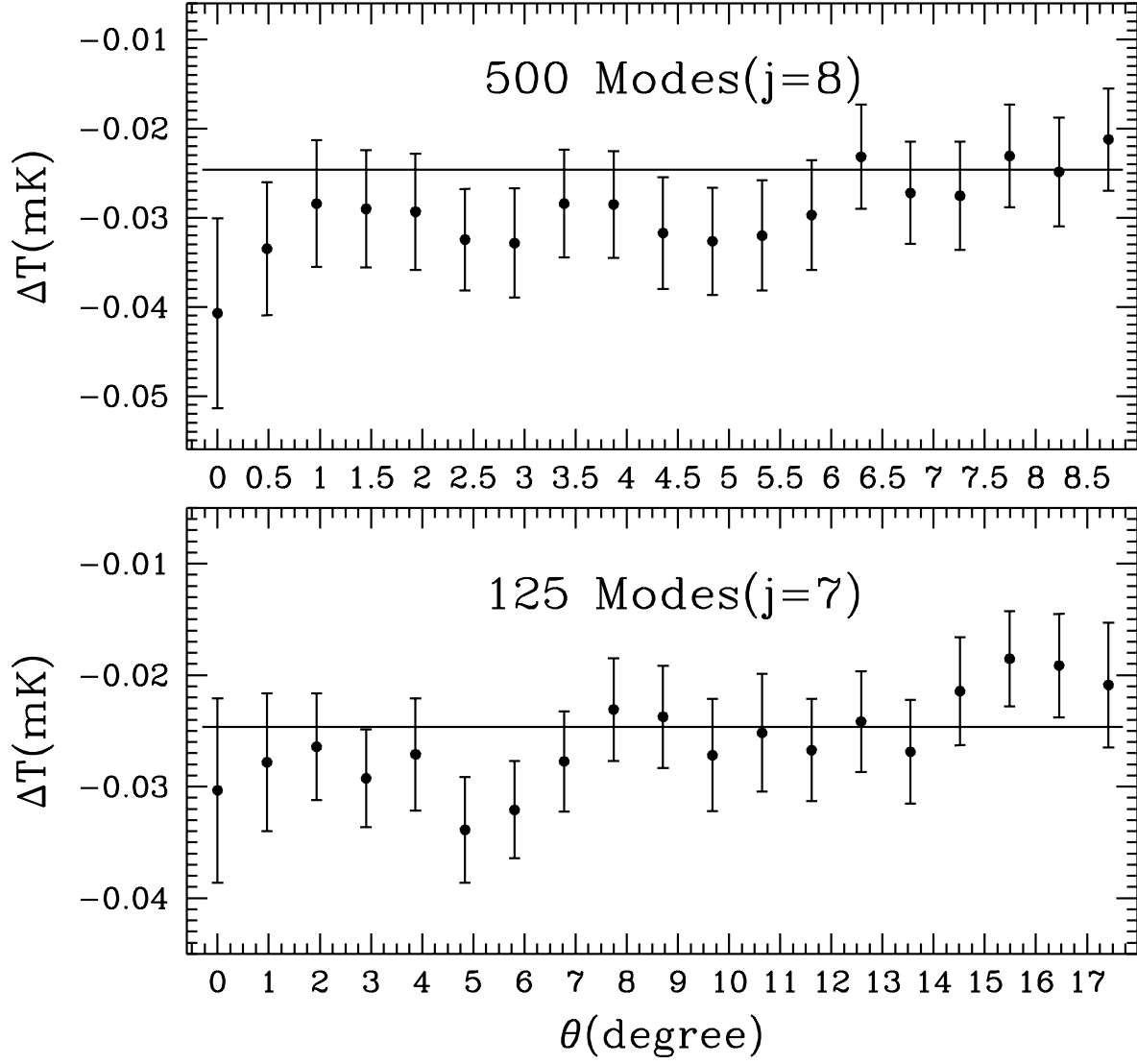
Xu, W., Fang, L.Z.,& Deng, Z.G. 1999 ApJ, 524, 1

Fig. 1.— Cross correlation $\langle T(|l-l'|)\rangle$ vs.θ between the WMAP map of W band and 2MASS DWT clusters.The top and bottom panels are, respectively, for top 500 $j = 8$ and 125 $j = 7$ DWT clusters.
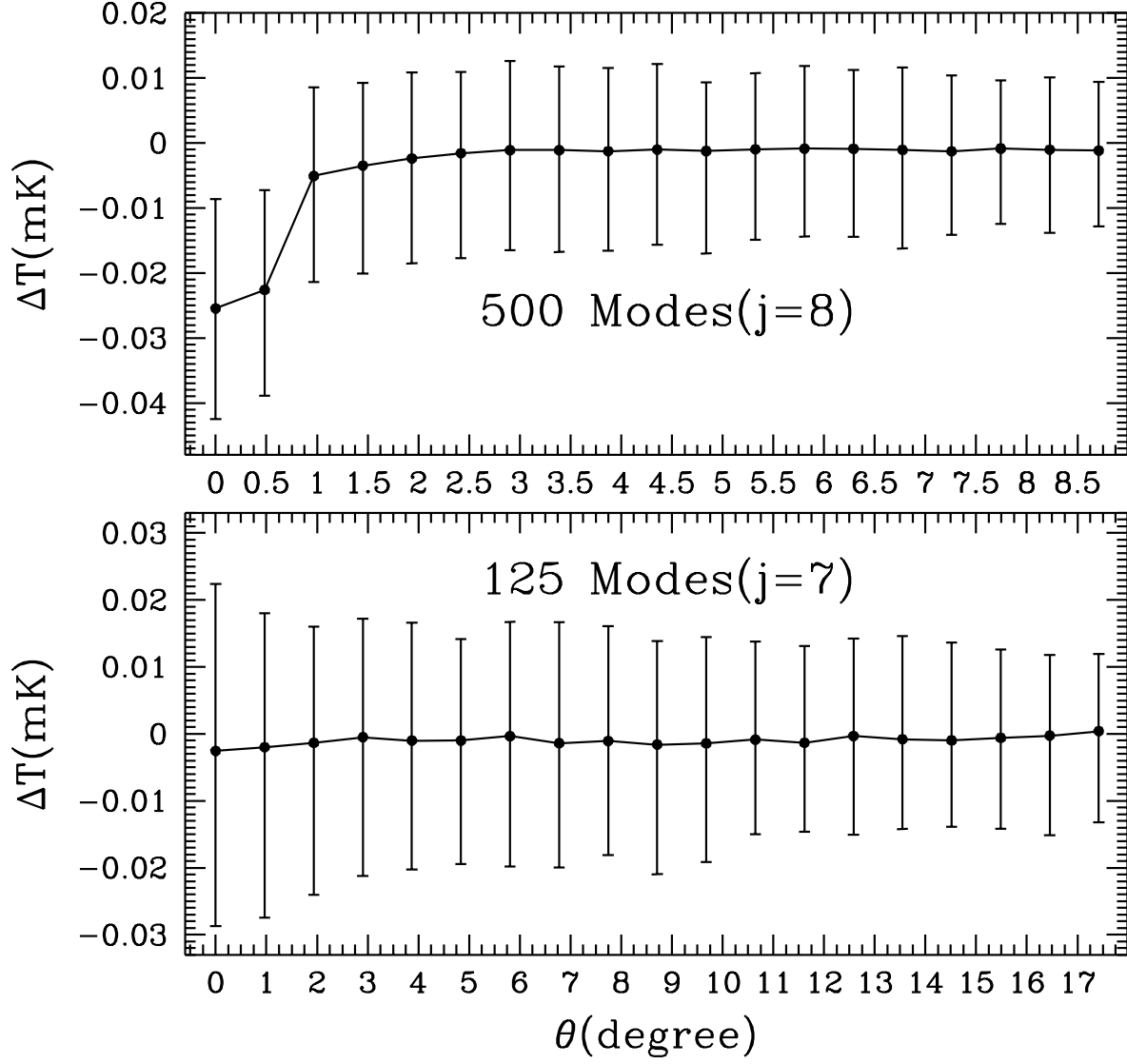
Fig. 2.— Cross correlation $\langle T(|l - l'|)\rangle$ vs.θ between the Mock SZ effect map and 2MASS DWT clusters. The top and bottom panels are, respectively, for top 500 $j = 8$ and 125 $j = 7$ DWT clusters.